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INTRODUCTION

In eastern Nevada and western Utah is an extensive terrane that has experienced a complex tectonic history of Mesozoic deformation and superposed Tertiary extension. The Mesozoic tectonic history of this area has been the subject of controversy for the past twenty or more years. The debate has centered on whether major Mesozoic geologic structures were due to compressional or extensional tectonic regimes. The goal of our research was to decipher the deformational history of the area by combining detailed geologic mapping, remote sensing data analysis, and U-Pb and K-Ar geochronology.

THE STUDY AREA

The study area includes the Dolly Varden Mountains and adjacent Currie Hills, located in the semi-arid environment of the northeastern Great Basin in Nevada. Vegetation cover in the Dolly Varden Mountains typically ranges from about 10% to 50%, with some places along drainages and on high, north-facing slopes where vegetation cover approaches 100%. Sagebrush is found at less vegetated lower elevations, whereas piñon pine and juniper are prevalent above 2,000 meters.

A variety of geologic materials is exposed in the study area. A sequence of Late Paleozoic and Triassic sedimentary rocks includes limestone, dolomite, chert, sandstone, siltstone and shale. A two-phase granitic stock, called the Melrose, intruded these rocks, resulting in metamorphism along the intrusive contact. Tertiary volcanic rocks cover most of the eastern part of the Dolly Varden Mountains and low-lying areas in the Currie Hills.

REMOTE SENSING DATA ANALYSIS

Data from several remote sensing instruments were processed and analyzed during the course of the study. Directional filters were made and convolved with Landsat Thematic Mapper (TM) data to enhance linear features striking in various directions. This technique delineated major faults and also provided evidence that some faults are more extensive than previously known. TM color composites were made using band ratios, principal component images, and decorrelation stretches. These scenes differentiate various igneous, sedimentary and volcanic units found in the area. In some scenes, areas where sedimentary rocks have been altered to hydroxyl-bearing minerals stand out.

Thermal Infrared Multispectral Scanner (TIMS) data taken over the Dolly Varden Mountains in 1986 were also processed and analyzed. A decorrelation stretch was applied to bands 1, 3 and 5 of the data and a color-composite image made. In this scene, carbonate rocks, felsic and intermediate volcanic rocks, and several intrusive bodies are discriminated.

Five flight lines of Airborne Imaging Spectrometer (AIS) data were acquired at the same time as the TIMS data. These data were first normalized using an equal energy spectral normalization technique that scales the sum of the digital numbers (DN's) in each spectrum to a constant value. This step removes albedo differences due to topographic effects. These data were then converted to reflectance using the

internal average relative reflectance (IAR) method. This conversion divides each pixel's spectrum by the average spectrum for the entire flight line. This method produces relative reflectance spectra that show features not common throughout the flight line. Thus, atmospheric absorption features common throughout are removed. The IAR conversion has an advantage in that no *a priori* knowledge of the geology of the area is required. However, this method can introduce peaks in relative reflectance spectra if the average spectrum for the scene contains an absorption feature that some pixels do not have. For example, in a scene where vegetation coverage is sufficient to produce a chlorophyll absorption feature in the average spectrum, pixels that do not contain vegetation will show an "anti-vegetation" peak in their reflectance spectra that mirrors the absorption feature in the average spectrum.

AIS reflectance spectra were compared to library mineral spectra included in Jet Propulsion Laboratory's Spectral Analysis Manager (SPAM) software. Calcite, dolomite, tremolite, montmorillonite and kaolinite were identified in the AIS data.

Five flight lines of Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data were collected over the Dolly Varden Mountains-Currie Hills area in 1989. The empirical line method was used to convert the AVIRIS data to reflectance. This method corrects for the multiplicative effects of solar irradiance, atmospheric attenuation and instrument response, as well as the additive factors of path radiance and instrument dark current. For this study, a dark andesite flow and a bright playa adjacent to the Dolly Varden Mountains were chosen as calibration targets. A Geophysical & Environmental Research Inc. Single FOV Infrared Intelligent Spectrometer (SIRIS) was used to take reflectance spectra of these targets.

AVIRIS color-composite scenes show areas where the sedimentary section has been deformed. On the east side of the Dolly Varden Mountains, northeast-striking faults that do not appear on published maps are evident in the imaging spectrometer data. Also on the east side of the range, a folded stratigraphic sequence is clearly evident.

Reflectance data from several AVIRIS scenes were analyzed and various minerals identified, including goethite, calcite and dolomite. This enabled the differentiation of certain limestone-dominated and dolomite-dominated formations. The distribution of these formations indicates that the sedimentary section has been folded.

To aid in the delineation of different rock units, pixels with spectra characteristic of various rock types were selected from the reflectance data and then, using a binary encoding algorithm, other pixels whose spectra matched within a certain tolerance were selected and color coded. These thematic images were then used to locate geologic structures to investigate in the field.

A linear unmixing routine was also applied to the reflectance data. A spectral library of "endmembers" was made by obtaining reflectance spectra of materials collected in the field. The library endmembers were then compared to each spectrum in a particular scene and the proportions of each library endmember found in each pixel were calculated. The result is a series of fraction images showing the areal distribution of each endmember.

The unmixing routine was applied to an area in the Currie Hills where the limestone-dominated Gerster Formation, the dolomite-dominated Plympton

Formation and Triassic shale and limestone of the Thaynes Formation are exposed. The library of materials used in the unmixing included limestone, dolomite, chert, dark brown limestone, intermediate volcanic rocks, and a mix of gray limestone and shale from the Thaynes Formation. Because the Thaynes limestone and shale are interbedded on a finer scale than the AVIRIS pixel size, this endmember spectrum was obtained from a mix of those materials.

The resulting fraction images generally show good differentiation between rock types. A color-composite scene of the limestone, dolomite and Thaynes fractions shows good agreement with formational contacts as mapped in the field. In some places, the fractions reflect the extent of significant amounts of colluvium and alluvium, and therefore do not exactly match the mapped bedrock contacts. However, the distribution of the three formations in the color-composite image indicates that the rocks are deformed.

Using the unmixing results and a vegetation spectrum obtained in the field, a routine was written and applied that subtracts the vegetation fraction from each pixel in a scene. The objective was to remove the vegetation component of the data in order to focus on geologic materials. This was accomplished by first multiplying the field vegetation spectrum by the fraction that represents the amount of vegetation present in a particular pixel. Then, the resulting fractional vegetation spectrum is subtracted from the pixel in the original reflectance scene. For example, if the unmixing routine showed that a certain pixel in the scene contains 50% vegetation, then the vegetation spectrum (representing 100% vegetation) would be multiplied by 0.5, resulting in a fractional vegetation spectrum. Then, the fractional spectrum would be subtracted from the original data.

After the vegetation component was removed, the data were looked at both spectrally and spatially. Spectra from the original data which contained vegetation lost the characteristic vegetation absorption features and their overall reflectance was generally lowered. In order to view the vegetation removal in a spatial context, color-composite images were made of AVIRIS data before and after the vegetation subtraction. In both data sets, a band centered near 0.8 μm was displayed as green. In the original reflectance data, areas containing significant vegetation have a green tint due to the high reflectance of vegetation at that wavelength. After vegetation subtraction, these areas are less green and drainages which contain close to 100% vegetation are almost black.

A binary encoding routine comparing spectra to a calcite library spectrum was run on both data sets. Many more pixels were matched correctly to the library spectrum in the data having the vegetation component removed, resulting in an improvement in the delineation of rock units.

FIELD WORK

To decipher the tectonic history of the study area, several areas of deformation were mapped and studied. The major folds, most of which occur in the Currie Hills, generally trend north-northeast, similar to major folds in other ranges in northeastern Nevada. Mapping has also shown the existence in the Dolly Varden Mountains of near-bedding-parallel faults that have cut out parts of the stratigraphic section. Cross-cutting relationships show that these faults formed prior to the Melrose intrusion.

The grant funded age dating of both the Melrose intrusion and the oldest volcanic rocks in the Dolly Varden Mountains. A U-Pb zircon age of 165 Ma was obtained on the intrusion, while a K-Ar hornblende age of 39.1 Ma was obtained on a basalt unit at the base of the volcanic section.

CONCLUSIONS

Our research has documented various Mesozoic folds and faults in the Dolly Varden Mountains-Currie Hills area. In general chronologic order, the major structures in the Dolly Varden Mountains are: near-bedding-parallel faults, north-trending folds, and high-angle, north-striking normal faults. These structures predate the Jurassic Melrose intrusion. The youngest strata involved in Mesozoic deformation in the study area are Early Jurassic in age. These time constraints indicate that significant deformation occurred during Jurassic time, probably beginning in the Middle Jurassic.

In 1991, U. S. Geological Survey geologists proposed that a Jurassic deformational event they named the Elko orogeny produced folds and thrust faults in northeastern Nevada. The results of our research provide further evidence for this orogeny, and indicate the styles of deformation prevalent in the Dolly Varden Mountains-Currie Hills area.